Long-term effect of no-tillage on soil organic matter fractions in rainfed Aragon (NE Spain)

Blanco-Moure N.[@], Gracia R., Bielsa A., López M.V.

Departamento de Suelo y Agua, Estación Experimental de Aula Dei, Consejo Superior de Investigaciones Científicas (CSIC). Apdo. 202, 50080. Zaragoza. Spain. @: nblanco@eead.csic.es

@ Corresponding Author

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SUMMARY

This paper assesses the long-term effect of no-tillage (NT) on soil organic carbon (OC) content and its distribution among different organic matter fractions in rainfed agrosystems of Aragón (NE Spain). Adjacent fields of NT, conventional tillage (CT) and natural soils (NAT) were compared in three different cereal production areas. In the soil surface, the higher OC content found in the NAT soils was due to the particulate organic matter. In the case of agricultural soils, in general, the fractions responsible for the OC increase under NT were the fine particulate organic matter and the mineral-associated organic matter occluded within stable microaggregates.

Keywords: Soil organic carbon, conservation tillage, particulate organic matter, mineral-associated organic matter.

Efecto a largo plazo del no laboreo sobre fracciones de materia orgánica del suelo en agrosistemas de secano en Aragón (NE España)

RESUMEN

En este trabajo se evalúa el efecto a largo plazo del no laboreo (NT) en el contenido de carbono orgánico del suelo (OC) y su distribución en diferentes fracciones de materia orgánica en agrosistemas de secano en Aragón (NE España). En tres diferentes zonas cerealistas se compararon campos adyacentes de NT, laboreo tradicional (CT) y suelo natural (NAT). En la superficie del suelo, el mayor contenido en CO encontrado en los suelos NAT se debió a la materia orgánica particulada. En el caso de los suelos agrícolas las fracciones responsables del incremento de OC en NL fueron, en general, la materia orgánica particulada fina y la fracción órgano-mineral de los microagregados estables.

Palabras clave: Carbono orgánico del suelo, laboreo de conservación, materia orgánica particulada, fracción órgano-mineral.

Efeito a longo prazo do plantio direto em frações de matéria orgânica do solo no sequeiro de Aragon (NE Espanha)

RESUMO

Este trabalho avalia o efeito a longo prazo do plantio direto (NT) no conteúdo de carbono orgânico no solo (OC) e a sua distribuição em diferentes frações da matéria orgânica em sistemas agrícolas de sequeiro em Aragon (NE Espanha). Campos adjacentes do NT, plantio convencional (CT) e solos naturais (NAT) foram comparados em três diferentes áreas de produção de cereais. Na superfície do solo, o maior teor de OC encontrado nos solos NAT deveu-se à matéria orgânica particulada. No caso dos solos agrícolas, as frações responsáveis pelo aumento de OC em NL foram, em geral, à matéria orgânica particulada fina e a fração organo-mineral de microagregados estáveis.

Palavras-chave: Carbono orgânico do solo, preparo conservacionista do solo, matéria orgânica particulada, fração organo-mineral .

INTRODUCTION

The loss of physical protection of organic carbon (OC) by soil aggregates (Denef et al. 2007), changes in soil oxygenation and microclimate (Balesdent et al. 2000) and reduced C inputs to the system (Golchin et al. 1995) have been identified as the main causes of the OC decrease in agricultural soils. However, conservation tillage and, more specifically, no-tillage (NT) may enhance OC accumulation in the soil surface compared with CT systems. Recently, López et al. (2009) evaluated the ability of NT to increase the soil OC content comparing 22 pairs of adjacent fields of NT and CT in different dryland cereal-growing areas of Aragon (NE Spain). In this work, Soil OC under NT was between 8% lower (only in one field) and 55% higher than that found under CT in the 0-20 cm layer. The higher impact of the NT duration as well as of other agriculture practices (cropping system, crop residues management, etc.) could mask the effect of other influential factors as climate and soil type. The aim of the present study was to further understanding of the contribution of different soil organic matter fractions to the OC increase observed under NT and, especially, of the role of soil microaggregates in the physical protection of OC in these farming systems.

MATERIAL AND METHODS

Fields of commercial farms with a large number of years under NT (9-21 years) were compared with adjacent CT fields in three different rainfed cereal areas of Aragon (Table 1). At each site, a NAT soil was also selected as a control soil.

Soil sampling (0-5, 5-20 and 20-40 cm depths) was made in three different zones within each field (NT, CT and NAT) where two soil samples were collected and mixed to make a composite sample. A total of 27 soil samples were taken from each site (3 fields x 3 depths x 3 replicates). Once in the laboratory, soil samples were subjected to physical fractionation, following the method of Six et al. (2000), to obtained 4 organic matter fractions: coarse particulate organic matter (cPOM, >250 μm in size), fine particulate organic matter (fPOM, 250-53 μm), mineral-associated organic matter occluded within stable microaggregates (Min-μagg, <53 μm) and easily dispersed mineral-associated fraction (Min-d, <53 μm). Soil OC content was determined by dry combustion with a LECO analyzer. Soil particle size distribution was obtained by laser diffraction analysis with a *Coulter LS230* laser grain-sizer.

Within each study site, statistical comparisons among treatments were made using one-way ANOVA, assuming a randomized experiment with the three sampling locations (i.e. sampling zones within each field) as pseudoreplicates (Christopher et al. 2009). Duncan's multiple range test was used to compare treatment means ($P < 0.05$).

Table 1. Characteristics of the agricultural fields. NT, no-tillage; CT, conventional tillage. Mb, mouldboard plough; Ch, chisel; Sb, subsoiler

Site (Province)	Mean annual precipitation (mm)	Soil type	Treatment	Soil and crop residue management
Lanaja (Huesca)	433	Silt loam *Calcaric cambisol* †	NT (14 years)	Crop residue retention
			CT	Mb. No crop residue retention
Artieda (Zaragoza)	741	Loam *Haplic regosol*	NT (21 years)	No crop residue retention
			CT	Ch. No crop residue retention
Torres (Huesca)	468	Sandy loam *Calcaric cambisol*	NT (9 years)	Crop residue retention
			CT	Mb/Sb/Ch. No crop residue retention

† WRB (2007).

RESULTS AND DISCUSSION

Tillage effect on total soil organic carbon.

As expected, the highest OC contents were found in the soil surface of the NAT soils (Figure 1) and especially in the Artieda site where more rainfall is received (Table 1). The fact that the NAT soil of Lanaja has been developed on an abandoned crop terrace (> 40 years) and the current passage of sheep can explain the relatively low OC content along the soil profile. In the agricultural soils, OC in the first 5 cm of soil was higher under NT than under CT in two of the study sites (Lanaja and Torres) with values of 13-15 g kg^{-1} vs. 10 g kg^{-1} in CT (Figure 1). In the Artieda site, the lack of differences between both treatments was due to the excessive removal of crop residues from the NT field and the use of the chisel plough in the CT treatment (Table 1). The differences among treatments decreased with soil depth due to both the homogenization of soil profile by mouldboard ploughing (CT) and the OC concentration gradient in undisturbed soils (NT and NAT soils). No effect of soil type was found on soil OC contents. This was probably due to the narrow texture range of the study soils (all medium textured soils). Likewise, mean annual precipitation did not seem to explain the differences in SOC under NT and CT among the study sites. Similar results were reported by Alvarez (2005) and Angers and Eriksen-Hamel (2008) for a wide range of soils, climate and tillage practices. In our study conditions, probably, a higher impact of other agricultural practices, as crop residues management or cropping intensity, could be masking the effect of other site characteristics.

Figure 1

Tillage effects on soil organic carbon fractions.

The easily dispersed mineral-associated fraction (Min-d) contributed most to the total OC content with percentages of 40-70 % (Figure 1). However, this fraction was not affected by tillage and no differences were found between NT and CT in any case. In contrast, at the surface layer, the fPOM-C and the Min-µagg-C were higher under NT than under CT, although not always these differences were statistically significant. The cPOM and fPOM fractions have been considered the first steps on the degradation of organic debris (Six et al. 2001). Once again, the lower effect of tillage on the fPOM-C in Artieda with respect to the other sites can be attributed to the low OC inputs from crop residues in NT and the use of the Ch plough in the CT treatment. As in the case of the total OC content, the fPOM-C was reduced with depth in all treatments and sites especially in NT that showed similar OC contents than CT in the 20-40 cm layer. Numerous studies point to an effect of tillage on the decay of fPOM due to the increase of rate of destruction of the aggregates (Balesdent et al. 2000) and, thus, the organic matter degradation (Denef et al. 2007). Likewise, a decrease in the formation of organo-mineral complexes within soil aggregates is often associated with the depletion of the fPOM fraction (Golchin et al. 1995). In fact, in the present study, the separation of the Min-µagg-C from the Min-d-C allowed us to assess the capacity of NT to enhance physical protection of OC within stable microaggregates in the soil surface.

CONCLUSIONS

In rainfed cereal areas of Aragon, the higher OC content found in the soil surface under NT than under CT is mainly due to the increase of fPOM and Min-µagg fractions. The physical protection that stable microaggregates offer to OC seems to be a main cause for long-term soil enrichment in organic matter resulting from the adoption of NT in these environments. Results from this on-farm study also indicate that a proper management of crop residues is essential for successful NT in rainfed Aragon, whose influence can be even greater than other factors such as precipitation or soil texture. However, further research in a broader scenario of soil type and climate is necessary to an accurate evaluation of the effect of NT on long-term OC stabilization in soils.

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Figure legend

Figure 1. Soil organic carbon (OC) fractions as affected by soil management (CT, conventional tillage; NT, no-tillage; NAT, natural soil). For the same fraction and soil depth, different letters indicate significant differences among treatments (*P* < 0.05).

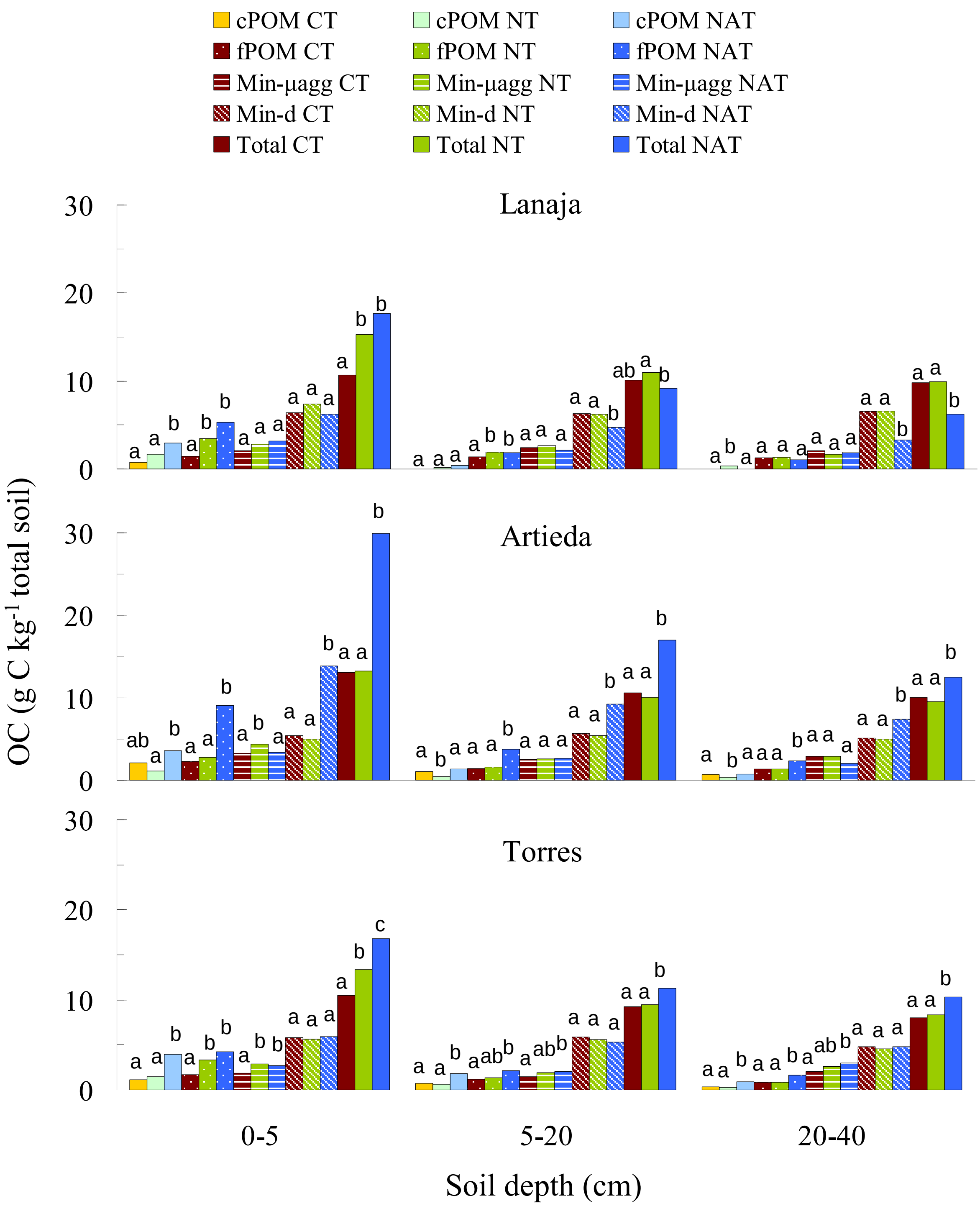
cPOM CT
cPOM NT
cPOM NAT
fPOM CT
fPOM NT
fPOM NAT
Min-µagg CT
Min-µagg NT
Min-µagg NAT
Min-d CT
Min-d NT
Min-d NAT
Total CT
Total NT
Total NAT
Lanaja
Artieda
Torres
OC (g C kg-1 total soil)
0-5
5-20
20-40
Soil depth (cm)

Fig. 1